INVESTIGATION ON DIFFERENT VERTICAL AERATED ROCK FILTER (VERTICAL AERATED ROCK FILTER) IN REMOVING PHOSPHORUS FROM DOMESTIC WASTEWATER

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A thesis submitted in fulfillment of the requirements for the award of the Degree of Master of Civil Engineering

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APRIL 2021

"I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged."

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Dedicated to my beloved mother, father, wife, brothers and all of my family members.

Also to my supervisors, technicians and friends

Thank you for all your support, help and motivation.

ACKNOWLEDGEMENT

Alhamdulillah, thanks to Allah S.W.T because with His permission I can complete this Master thesis. I also would like to express my sincere appreciation to my supervisor PM. Dr. Rafidah Binti Hamdan because of her encouragement, guidance, trust, critics and ideas in helping to finish my Master's project.

I also would like to express my special thanks to all the staff in FKAAB Environmental Laboratory, Wastewater Engineering Laboratory, Analytical Laboratory and Chemical Engineering Laboratory because of their help and assistance given to me during laboratory testing along with material given.

My special thanks and regards to my beloved mother Nora Binti Yasin, my treasured father Maarup Bin Burok, my brothers and all of my family members for their support, patience and financial support during the completion of this Master's project.

Finally, my appreciation to my lovely wife Izzati Izwanni Binti Ibrahim and my friend for their support and advice. Thanks for everything.

Thank you.

ABSTRACT

Nutrients in the water body encourage the growth of algae which can accelerate eutrophication. Rock filter (RF) has appeared as an alternative technology to remove phosphorus from wastewater**.** In response to this, the selection of media between steel slag and limestone for pilot scale filter has been investigated by receiving the same volumetric hydraulic loading rate and airflow rate. Based on the analysis, steel slag emerged as the best media in removing the selected parameters. Therefore, the vertical aerated steel slag filter (VASSF) has been optimized with different hydraulic loading rates (HLR) ranging from 0.16 to 5.44 m^3/m^3day and airflow rate ranging from 3L/min to 10L/min to enhance the removal of phosphorus. Based on the optimization study, total phosphorus (TP) removal was perfectly removed by using an airflow rate of 7L/min and HLR of 1.04 m^3/m^3.day. The VASSF was efficiently removed by 89%, 75%, 73%, 30% and 96% of biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), TP and total coliform respectively. Meanwhile, for the pH, the effluent value decreased by 56%, pH also rose to 7.3 and dissolved oxygen (DO) concentration increased up to 5.09 mg/L. Result from steel slag lab-scale study shows that for selected parameter was removed by about 99%, 94%, 97%, 58% and 96% meanwhile for limestone lab-scale study removed by about 95%, 94%, 98%, 64% and 100% of BOD, COD, TSS, TP and total coliform respectively. The mechanism for phosphorus removal study by using scanning electron microscopy (SEM/EDX) equipment has been conducted after a period of two months for testing. For the fresh steel slag sample, there is no phosphorus on the surface but for the treated steel slag sample, there are available on the surface. Based on phosphorus attachment on media it indicates that the adsorptions occur on the media and all parameters are in the permissible limit of standard B based on Malaysian Environmental Quality (Sewage) Regulation 2009.

ABSTRAK

Nutrien dalam air menggalakkan pertumbuhan alga yang boleh mempercepatkan eutrofikasi. Penapis batu (RF) muncul sebagai teknologi alternatif bagi menyingkirkan fosforus dari air sisa. Pemilihan media antara sanga keluli dan batu kapur untuk penapis skala kecil telah dijalankan dengan meggunakan kadar aliran hidraulik volumetrik dan aliran udara yang sama. Berdasarkan kajian analisis, sanga keluli muncul sebagai media terbaik dalam menyingkirkan parameter yang dipilih. Oleh itu, penapis berudara sanga keluli menegak (VASSF) telah dioptimumkan dengan kadar aliran hidraulik yang berbeza (HLR) antara 0.16 hingga 5.44 m^3/m^3hari dan kadar aliran udara dari 3L/min hingga 10L/min bagi menyingkirkan fosforus. Berdasarkan ujian penentuan optimum, total fosforus (TP) dapat disingkirkan menggunakan kadar aliran udara 7L/min dan HLR 1.04 m^3/m^3hari. VASSF masing-masing telah menyingkirkan kira-kira 89%, 75%, 73%, 30% dan 96% permintaan oksigen biokimia (BOD), permintaan oksigen kimia (COD), jumlah pepejal terampai (TSS), TP dan kolifom. Sementara itu nilai pH menurun kira-kira 56%, pH meningkat hampir 7.3 dan kepekatan oksigen terlarut (DO) meningkat sehingga 5.09 mg/L. Hasil daripada kajian makmal, sanga keluli menunjukkan bahawa parameter terpilih telah disingkirkan masing-masing antara 99%, 94%, 97%, 58% dan 96% sementara itu bagi batu kapur masing-masing antara 95%, 94%, 98%, 64% dan 100% bagi BOD, COD, TSS, TP dan total kolifom. Kajian mekanisme penyingkiran fosforus menggunakan peralatan pengesanan mikroskop elektron (SEM / EDX) telah dijalankan selepas tempoh ujian dua bulan. Bagi sampel sanga keluli baru, tiada fosforus di permukaan tetapi bagi sampel sanga keluli terpakai, terdapat fosforus di permukaan. Berdasarkan lekatan fosforus pada media, ia menunjukkan bahawa penyerapan berlaku di media dan semua parameter berada di had yang dibenarkan standard B berdasarkan Peraturan Kualiti Alam Sekitar Malaysia (Kumbahan) 2009.

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LIST OF ABBREVIATION

ASSF	-	Aerated Steel Slag Filter
BOD_5	-	5-days Biochemical Oxygen Demand
COD	-	Chemical Oxygen Demand
DO	-	Dissolved Oxygen
HRT	-	Hydraulic Retention Time
HLR	-	Hydraulic Loading Rate
L	-	Liter
m	-	Meter
min	-	Minutes
mg	-	Milligram
ml	-	Millimeter
P	-	Phosphorus
PVC	-	Polyvinyl Chloride
Q	-	Flow rate
TP	-	Total Phosphorus
TSS	-	Total Suspended Solid
UTHM	-	Universiti Tun Hussein Onn Malaysia
VARF	-	Vertical Aerated Rock Filter
LSSSF	-	Lab Scale Steel Slag Filter
LSLSF	-	Lab Scale Limestone Filter

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Superfluous amounts of nutrients from the inorganic elements such as nitrogen, phosphorus, calcium, magnesium are considered a major nutrient expulsed from the domestic sewage effluent (Ling and Lee, 2016). Phosphorus is one of the main nutrients released that could lead to eutrophication process in the river and in turn, affecting the water body. The phosphorus acting as a fertilizer to aquatic plant and can accelerate the growth of the plant. The presence of this nutrient in the water body would threaten the aquatic lives in the river, as stated by WHO, 2002 with even a small increase in phosphorus which could be as low as 0.01mg P/L, it would cause eutrophication that can cause excessive growth of phytoplanktons. A larger proportion of these nutrients such as phosphorus and nitrogen entering into the water body may increase purification costs that could lead to the large traces of algal toxins in drinking water. Besides that, eutrophication can lower dissolved oxygen in the water body thus will cause the water to be unsuitable for aquatic life. Phosphorus being the factors that make the level of eutrophication increase and the excessive effluent discharge of phosphorus may accelerate the eutrophication process and lead to deterioration of water quality in the river including depletion of dissolved oxygen in water, algae bloom and stimulating the activities of harmful microbes.

There are many methods that have been applied such as chemical, physical and biological systems to control the nutrients discharged from the wastewater treatment system and advanced wastewater treatments that are required to remove phosphorus from wastewater. The stringent outlet standard leads to the usage of advanced technologies for pollutant removal. Some parts of the country are still applying the higher outlet standard which is more than 1 mg/L and still cannot eliminate the excessive nutrient from the environment (Marek, Ondřej, Eliška *et al.*, 2012). Additionally, advanced treatment system should be serviced by a qualified service person and they will clean or replace the filters as required because of all specified level of water quality could be achieved via a combination of mechanical operation; however all of this requires a lot of energy, high cost and requires highly skilled workers. Therefore, an alternative method for phosphorus removal from domestic wastewater is needed.

Rock filters (RF) emerged as one of the attractive natural wastewater treatment methods to treat wastewater high in nutrients. Initial research on the RF system has been developed in Kansas University in the early 1970s as an alternative treatment for suspended solids (SS) and biochemical oxygen demand (BOD) from the wastewater effluent. Even though the RF removes the previously mentioned parameters efficiently but it does not remove ammonia as the RF system condition has been rapidly changed to anoxic condition. This is due to the un-aerated RF system becomes anoxic and it is unable to remove ammonia by nitrification process (Reed *et al.*, 1995). Ammonia can be reduced by inducing air in the RF which can lower the concentration by nitrification process. However, later in the United Kingdom, Aerated rock filter (ARF) developed by Mara (2006) becomes an alternative method to treat the BOD_5, suspended solids (SS), ammonia, and COD. Consequently, from this research, the performance of ARF by using aeration eliminates NH_3 which improves BOD and SS removal from wastewater. This process is also treating ammonia by the nitrification process. Besides that, the rock filter with aeration also has great potential in removing blue-green algae proliferation and eutrophication (Ibrahim, 2017). Meanwhile, in 2007, ARF has been used to remove phosphorus by using limestone and blast furnace slag (BFS) as it has a potential in removing mechanism based on adsorption and precipitation by media. According to Deng & Wheatley (2018), the substrates containing iron (Fe), aluminium (Al) and calcium (Ca) are strong adsorbent for nutrients removal expecially for phosphorus.

Mambo *et al.* (2014) stated that the maturation ponds became an additional polishing to remove any residual pathogens and becoming the best method in polishing the effluent. ARF is also has been used to remove ammonia and fecal coliform in the facultative pond. Aeration in ARF improves the biodegradable organic matter such as BOD removal, fecal coliform, ammonia and also suspended solid regardless of the incoming flow direction (Rafidah Hamdan and Mara, 2013). According to Wang et al. (2016), the application of waste materials such as steel slag and shell decreased the nutrient concentration in the surface water. Additionally, an extensive study for phosphorus removal has been carried out by Hamdan & Mara, (2013) in the UK by using blast furnace slag (BFS) in low cost vertical and horizontal ARF. A result from present research indicates that the rate of P-removal achieved about an average of 88% for both vertical and horizontal BFS filter. It shows that the BFS filter is very effective in treating primary facultative pond effluents at temperate climate and also capable in removing nutrient from wastewater. However, this system has not been tested for domestic wastewater under a warm climate (Malaysia). ARF will become an appropriate application in a wastewater treatment system and will be an ideal option for phosphorus removal from wastewater in a small community. Besides, secondary treatment in the wastewater treatment plant can be upgraded by using ARF system. Hence, it will reduce the eutrophication process by removing these nutrients from the wastewater.

Therefore, the focus of the ARF system in this study is to enhance phosphorus removal in the RF to treat the wastewater in the treatment plant under a warm climate. The experimental work has been carried out by using two types of systems; lab scale filter (limestone and steel slag) and pilot-scale filter. The first stage for the study is to filter media selection by comparing steel slag and limestone in the lab-scale filter to get the most effective media in removing P from wastewater. Afterwards, for the second stage of the study, the best filter media found from the lab-scale study has been used as a filter media in a pilot-scale. A monitoring study has been conducted on removing P from wastewater by using a lab-scale and pilot-scale filter.

In addition, a new stricter requirement for wastewater effluent in Malaysian under the Environmental Quality Act (Sewage) Regulation (2009) requires acceptable phosphorus discharge in the nearby river to be limited to 5.0 mg/L for standard A and 10.0 mg/L for standard B. The permissible effluent should be lowered for the future to make the standard a very strict limit for the effluent discharge.

1.2 Problem Statement

Wastewater containing phosphorus could lead to eutrophication which can cause rapid growth of algae bloom in the water. Hence, to treat these nutrients the cost is considered too high due to high levels of geosmin that developed in the water because of the chemical released by blue-green algae (Biosurvey, 2013). Almost 38% of public wastewater treatment plants in Malaysia are using mechanical instruments and all these plants operated by mechanical instruments is to accelerate sewage break down (Indah Water Consortium, 2014). The cost for components differ depending on size, plant type and electricity is a major cost when using mechanical instruments. The new technology of phosphorus removal such as filtration by using waste material becomes necessary due to the increasing demand for stricter effluent discharge to prevent eutrophication and sludge disposal restriction (Li *et al.*, 2013).

Phosphorus in excessive presence will make the rapid growth of algae and become eutrophication which in disturb the human food and aquatic life (Abdul Ghani, Mahmood and Othman, 2019). It is also make the water body become paralyse, reduce human immunity system and become the choronic effect to the aquatic marine life. Hence the presence of phosphorus in water body need to be controlled based on the Malaysian regulation standard.

Advanced wastewater treatment includes nutrients removal, heavy metals and further removal of suspended solids and organic. This treatment requires a very high standard of treatment because it is being discharged into an already fragile water body. Sludge from advanced treatment is suitable to reuse and treated water can be discharged into a stream or river. In addition to this, it can also be used as groundwater recharge or agriculture purposes. Besides, tertiary treatment is more expensive to develop and may increase maintenance costs and need high skill workers. According to Indah Water Consortium (2014), there is no plan to build tertiary treatment systems in Malaysia because it is an expensive endeavor. There is a standard of preliminary, primary and secondary treatment in the Indah Water Consortium treatment system that need to follow. In Malaysia, the treatment plant is only focusing to provide a basic standard of preliminary, primary and secondary treatment due to high cost to provide the tertiary sewage treatment. Hence, the new waste filter media technologies must be developed to replace the tertiary treatment for the existing treatment systems for treating nutrients in wastewater.

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